DISTRIBUTION OF TURBIDITY IN AUSTRALIAN TROPICAL WATERS

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P.J. MULHEARN

MRL-TN-638

AUGUST 1993

MATERIALS RESEARCH LABORATORY

DSTO

Distribution of Turbidity in Australian Tropical Waters

P.J. Mulhearn

MRL Technical Note
MRL-TN-638

Abstract

Data on underwater visibility in tropical Australian waters, in the form of Secchi disc depths and light attenuation coefficients have been collected and are presented in the form of maps with Secchi depths grouped in the ranges: less than 5 m, 5 m to 10 m, and greater than 10 m. As one would expect there is a general trend for water turbidity to decrease (or Secchi depth to increase) with depth, and for turbidity to be high in areas with a large tidal range. It can be seen, from the maps, that high turbidity would not infrequently limit diver and remotely operated vehicle operations along Australia's northern coastal shipping routes and in major port approaches.

DEPARTMENT OF DEFENCE
DSTO MATERIALS RESEARCH LABORATORY

Published by

DSTO Materials Research Laboratory
Cordite Avenue, Maribyrnong
Victoria, 3032 Australia

Telephone: (03) 246 8111
Fax: (03) 246 8999

AR No. 008-262

APPROVED FOR PUBLIC RELEASE

Contents

Distribution of Turbidity in Australian Tropical Waters

1. Introduction

In mine clearance operations there are times when diver and remotely operated vehicle operations are severely hampered by poor underwater visibility. In order to assess the extent to which this would be a problem in continental shelf waters off northern Australia, available Secchi disc data were analysed to obtain the broad geographical variation of water turbidity, from North West Cape to Gladstone. Although Secchi depth data have their limitations, more of them are available than of any other type of turbidity data. At a small number of locations it was also possible to obtain the statistical distribution of Secchi depth.

Secchi depth is the depth to which a white disc, typically 30 cm in diameter, is visible from the sea surface. It is a measure of near-surface turbidity and will only be representative of the near-bottom turbidity, relevant to mine-clearance operations, when the water column is well mixed. Conditions under which this occurs and the relation between Secchi depth (a visibility range when looking vertically downward) and horizontal visibility range are discussed below.

A Secchi depth climatology, such as this, is useful for assessing the overall extent to which poor visibility will inhibit mine-clearance operations and thus has some bearing on the choice of equipment to be purchased by the RAN. For mine clearance operations in any particular area, a knowledge of typical visibility conditions would influence the types of equipment deployed.

Previously published work on turbidity in northern Australian waters, determined optically rather than as sediment concentration, can be found in Fielding and Jones (1979), Hamilton (1992), Ikeda *et al.* (1979), Orr (1933), Wolanski *et al.* (1981) and Mulhearn (1989). The last considers Torres Strait, but all the others are concerned with conditions in the Great Barrier Reef region. A world-wide Secchi depth atlas was produced by Arnone (1985), with average monthly Secchi depth displayed in 1° squares. The data available to Arnone were very sparse and he would not have had access to most of those used herein. In addition his use of averages over 1° squares would have smoothed out any cross-shelf variations, even where adequate data were available. The region to the north and north-west of Australia is covered by Murdock (1980).

2. *Data Sources*

Secchi depth data were obtained from the Australian Oceanographic Data Centre (AODC), reports by Ikeda *et al.* (1979) and by Orr (1933), research cruises of the former Underwater Systems Division (now Maritime Operations Division) of MRL, and the MRL field station at Innisfail, Queensland. Data on extinction coefficients, k, for ambient light, were also obtained from the Northern Territory Port Authority and from Forde (1985), and these were transformed into Secchi depths using the formula

$$\text{Secchi depth} = 1.45/k,$$

from Walker (1981).

The AODC's data from northern waters come from around the Queensland coast and from the area between Barrow and Thevenard Islands on the Northwest Shelf. The AODC's data were all obtained from RAN ships. The data from the MRL station at Innisfail and in Ikeda *et al.* (1979) and Orr (1933) consist of data obtained on a large number of occasions from a small number of discrete sites, within the Great Barrier Reef. Data for the approaches to Darwin were obtained from the NT Port Authority and MRL cruises, and for the approaches to Dampier from Forde (1985) and from one DSTO cruise. Data were also obtained during MRL cruises in the northern Great Barrier Reef, Torres Strait and in the approaches to Broome and Port Hedland. The data of Fielding and Jones (1979) were obtained with a transmissometer with broad wave-number band-width in the visible to infra-red region of the radiation spectrum. Because of the difficulties in comparing their results with Secchi depth values, for which there is a larger data base, Fielding and Jones's results are not used here.

The Secchi disc data used in this report are available from either the AODC or MRL.

3. *Horizontal Visibility Versus Secchi Depth*

From Williams (1970) horizontal visibility range, V, is inversely proportional to attenuation coefficient, c, i.e.

$$V = A/c,$$

where A is a constant. In practice A varies from approximately 6 to about 2.5, depending on background luminance and object size. Williams calculated the maximum value of A to be 5.82, but reports that the usual rule of thumb is

$$V = 3.5/c. \qquad (1)$$

Hojerslev (1986) found that for monochromatic light:

$$D \doteq 6.3/c, \qquad (2)$$

where D = Secchi depth.

In turbid waters, which are those of most concern here, attenuation is dominated by scattering, and c is independent of wavelength, to a good approximation in the visible region of the radiation spectrum (see, for example, Phillips and Scholz, 1982, Fig. 5). Hence equation (2) should also apply for broad-band measurements such as those of Secchi depth. Eliminating c from equations (1) and (2) gives:

$$V \doteqdot 0.6\,D,$$

and so visibility ranges of 3 m and 6 m correspond, approximately, to Secchi depths of 5 m and 10 m respectively. In the maps presented here Secchi depths are presented in three intervals: $D \leq 5$ m; $5\text{ m} < D \leq 10$ m; $D > 10$ m.

4. *Discussion of Turbidity Within Mapped Areas*

The maps are presented in order going anti-clockwise around northern Australia. Where no data are available no maps have been prepared. There are some data within a small area in Gove Harbour, which did not seem worth including on a map, and there are data from Joseph Bonaparte Bulf and in shallow areas north of Melville Island, which are not presented here because of the relative unimportance of those areas for defence purposes.

Great Barrier Reef:

Cairns to Mackay 17°S to 21°S (Map 1)

South of 18°S not much Secchi disc data are available, except at three stations off Townsville (Ikeda *et al.* 1979), but there appear to be no reasons why the broad conclusions of Hamilton (1992) for the region from 12°S to 18°S should not hold for this region as well (see below). At the stations off Townsville (see Map 1) data were obtained at approximately weekly intervals, for two years at stations 1 and 3, and for three years at station 2. Histograms showing the variability in Secchi depth at these stations are displayed in Figure 1. Secchi depth is less than 5 m on 66% of occasions at station 1, where water depth was 9 m, but always greater than 5 m at stations 2 and 3, where water depths were approximately 26 m and 40 m, respectively. Secchi depths were greater than 10 m on 2% of occasions at station 1, 90% of occasions at station 2, and 100% of occasions at station 3. There is no sign of seasonal variations at any of these three stations. Offshore of Townsville, Wolanski *et al.* (1981), likewise found no seasonal variation in transmissivity, and they generally found little stratification of transmissivity with depth. However, clear, less saline water appears to have migrated shorewards at the surface, on one occasion, causing stratification in temperature, salinity and transmissivity. Walker and O'Donnell (1981) found in Cleveland Bay, off Townsville, a linear regression ($r = 0.73$) between attenuation coefficient (inversely proportional to Secchi depth) and wind speed-run over the previous 24 hours. Water depth at their station was 10 m.

12° to 18°S: Lizard Is. to Innisfail and Wreck Bay to Barrow Pt. (Maps 2 and 3)

For the Great Barrier Reef region from 12°S to 18°S Hamilton (1992) concluded, after examining the available Secchi disc values, that "all values of less than 5 m were found inshore of the 20 m depth contour" and all values over 10 m were found "seawards of the shoreward limit of the inner platform and shelf reefs. Only near 14°30'S, 145° - 145°05'E were Secchi depths less than 5 m found distributed offshore, these being 2 to 4 n.miles south of a group of islands and reefs in depths less than 10 m". He also found that "Secchi disc depths broadly show a simple pattern, being linearly related to bottom depth, with contours parallel to shore, forming cross-shelf gradients." He concluded from surveys in March 1989 that "Turbidity over nearly the full water column for (the region offshore from) Cooktown to Innisfail can be directly inferred from Secchi disc depths since transmittance contours in cross shelf sections are vertical to the bottom." He did, however, find stratification in turbidity in the mid-lagoon area of Princess Charlotte Bay. The maps presented herein for 12°S to 15°S (Map 3) and for 14°S to 18°S (Map 2) are simply taken from Hamilton (1992). These findings agreed with Walker (1981) who found a linear regression relation (r = 0.98) between time-averaged Secchi depth and water depth for the region between Townsville (19°15'S) and Low Islets (16°24'S, 145°36'S).

Temporal variability of Secchi depth can be obtained from two locations, between 14°S and 18°S. Orr (1933) measured Secchi depth, approximately weekly, for one year in the vicinity of Low Islets, which are close to the 20 m depth contour and just inshore of the main shipping channel. A histogram of Orr's results is included in Figure 1. It can be seen that Secchi depth is less than 5 m on only 9% of occasions, and greater than 10 m on 51% of occasions. Another long series of measurements (138 observations over 13.5 years) has been obtained by MRL in the North Barnard Islands, which are near 17°40'S just inshore of the 20 m depth contour. The site is an area in the middle of a group of islands whose water depth varies between 3.5 and 8.5 m, and at times the bottom is visible from the surface. The Secchi depth was less than 5 m on 12% of occasions.

Adolphus Channel to C. Melville 10°30'S to 12°S (Map 4)

The amount of data is small here, but the available data are compatible with the broad conclusions of Hamilton (1992) for the 12° to 18°S region, and there appear to be no reasons why the same conclusions should not apply in this region as well. Adolphus Channel, near 10°45'S, 142°40'E, is a region of very high tidal currents and persistently high turbidity

Torres Strait and Off Fly River (Maps 5 and 6)

Secchi depth values less than 5 m are found at times throughout the area from off the Fly River to Thursday Island (near 10°30'S, 142°10'E), especially in the area north-west of the Great Northeast Channel (GNEC), the main shipping channel to the north-east. The observed variability in turbidity is temporal as well as spatial, but there is a tendency for Secchi depth to increase eastward of the GNEC. Throughout most of the Torres Strait, east of Thursday Island, turbidity

is constant with depth, except in very turbid areas where Secchi depth is less than 3.5 m, and in the deeper area towards the northern end of the GNEC. In the very turbid areas turbidity generally increases with depth and at times there are subsurface maxima. In the northern end of the GNEC ocean water from the Coral Sea intrudes at times close to the sea floor and there can be a layered structure in the turbidity profile (Mulhearn, 1989). West of Thursday Island Secchi depths of over 10 m are more common, but to the south-west low Secchi depths are found.

Eastern Gulf of Carpentaria - Endeavour Strait to Weipa (Map 7)

In this map the low Secchi depths south-west of Thursday Island can be seen to extend over a considerable area down to 11°30'S. Similarly around Weipa, from 12°30'S to 13°25'S Secchi depths are generally low. The available data suggest Secchi depths are low throughout the whole of the area south of 11°S and within 20 to 25 n.miles of the coast of the Cape York Peninsula.

Approaches to Darwin (Map 8)

Secchi depths less than 5 m have been found around the south-west corner of Bathurst Island, and in the south-east of Beagle Gulf (the gulf between Bathurst/Melville Islands and Darwin). Within 20 n.miles of Darwin Secchi depths as low as 2 m are common. LANDSAT satellite imagery indicates that waters are highly turbid out to approximately 10 n.miles offshore, all around Bathurst and Melville Islands. Clarence Strait, between Melville Island and the mainland is known to be an area of high tidal currents and of high turbidity.

Turbidity profiles are only available at or near to the positions where Secchi depth measurements have been taken. It was found that turbidity tended to increase with depth at the positions along 12°20'S, but was nearly constant with depth elsewhere. Along the shipping channel leading into Darwin, south of 12° 20'S, turbidity also increases with depth.

The Northwest:

Approaches to Broome (Map 9)

The few data for Broome's approaches were obtained on 2 and 3 December 1990, before the wet season had broken. It is not known how representative they are. The shipping channel here comes down 122°10'E and around Ganheaume Pt. into Broome. Along this route and at a few points further west, but east of 122°05'E, Secchi depths were less than 5 m. Secchi depths were generally greater than 10 m from 121°05'E westward. LANDSAT satellite images also show high turbidity close to the coast, and also within the bay east of Ganheaume Pt.
Transmissometer profiles showed that turbidity was nearly constant with depth at most locations, but there was some increase with depth at a few of the stations along 122°10'E.

Approaches to Port Hedland (Map 10)

Data for Port Hedland's approaches were obtained on 9 and 10 December 1990. Secchi depths less than 5 m were found close to Port Hedland, and northward as far as 20°00'S. North of 20°S all Secchi depths were greater than 10 m. The overall tendency is for Secchi depth to increase with water depth. LANDSAT satellite images often show turbid waters from the coast out to approximately the 10 m depth contour. Turbidity was found to be constant with depth north of 20° S, and to increase with depth at all stations south of 20°10'S. Between these limits some profiles showed turbidity increasing with depth and some did not. At 20° 05'S, 118°40'E turbidity decreased as depth increased.

Approaches to Dampier (Map 11)

The data for Dampier's approaches come from Forde (1985), who presents results obtained from April 1982 to December 1983, and from one MRL cruise in November 1989. No data are available on the variation of turbidity with depth. Secchi depths less than 10 m were found at times near Dampier, but become greater than 10 m as one moves northward.

Barrow Is. to Thevenard Is. (Map 12)

The data in this area were obtained at various times from January to August 1988, by HMAS Moresby. Secchi depths were greater than 5 m on all but one occasion, and values greater than 10 m were common. Because of the limited amount of data available little more can be said here. There is no information on variations of turbidity with depth. The coastal shipping channel here approximately follows a line from 21°30'S, 115°00'E north-eastward to 21°12'S, 115°30'E, and then to 21°00'S, 115°34'E.

5. *Summary*

Underwater visibility ranges of less than 3 m correspond to Secchi depths less than 5 m. Such conditions are known to often occur in the following locations:

the Great Barrier Reef lagoon for water depths less than 20 m;
eastern Torres Strait;
the mouths of the Fly River;
Endeavour Strait;
the approaches to Weipa;
the approaches to Darwin;
within 10 n.miles of the coasts of Bathurst and Melville Islands;
Clarence Strait;
the nearshore approaches to Broome, Port Hedland and Dampier.

Most of these places are important either for shipping or defence and the laying of mines in them would be very disruptive. The low underwater visibility found at these locations would severely hamper mine clearance operations which used either divers or remotely operated vehicles equipped with TV or video cameras.

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II. Seasonal variations. *Australian Journal of Marine and Freshwater Research*, 32, 321.

Table 1: List of Maps

Great Barrier Reef:
- Cairns to Mackay 17°S to 21°S
- Lizard Is. to Innisfail 14°S to 18°S
- Wreck Bay to Barrow Pt. 12°S to 15°S
- Adolphus Channel to C. Melville 10°S to 15°S

Torres Strait

Off Fly River

Eastern Gulf of Carpentaria - Endeavour Strait to Weipa

Approaches to Darwin

The Northwest:
- Approaches to Broome
- Approaches to Port Hedland
- Approaches to Dampier
- Barrow Is. to Thevenard Is.

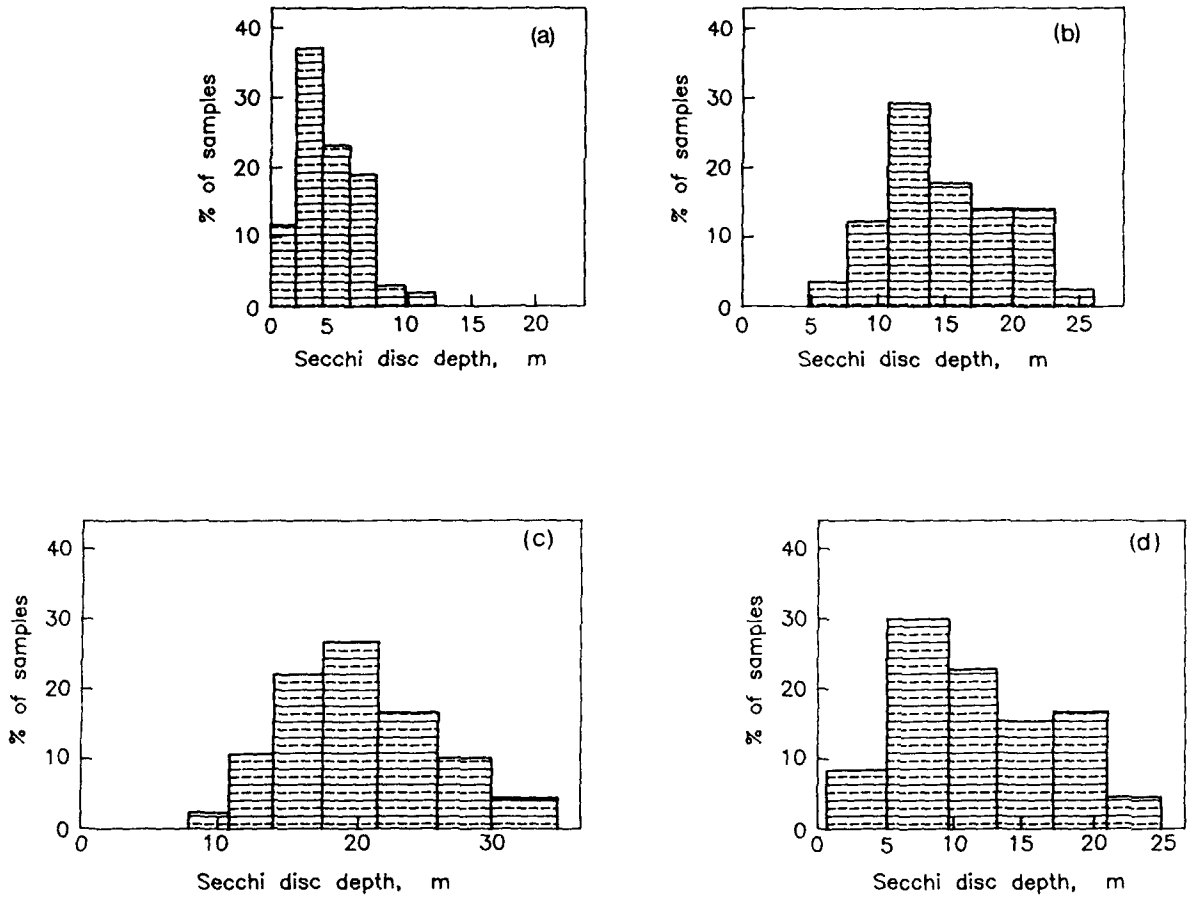
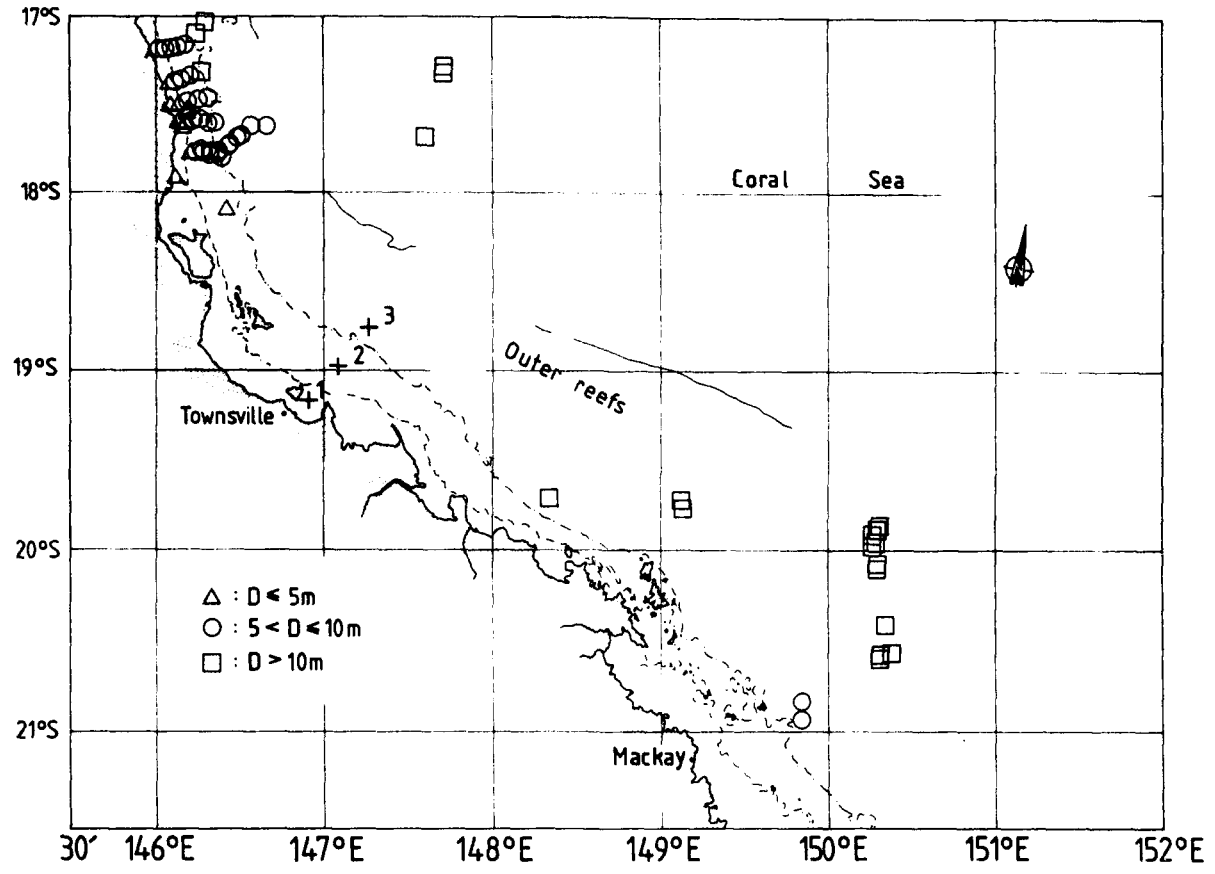
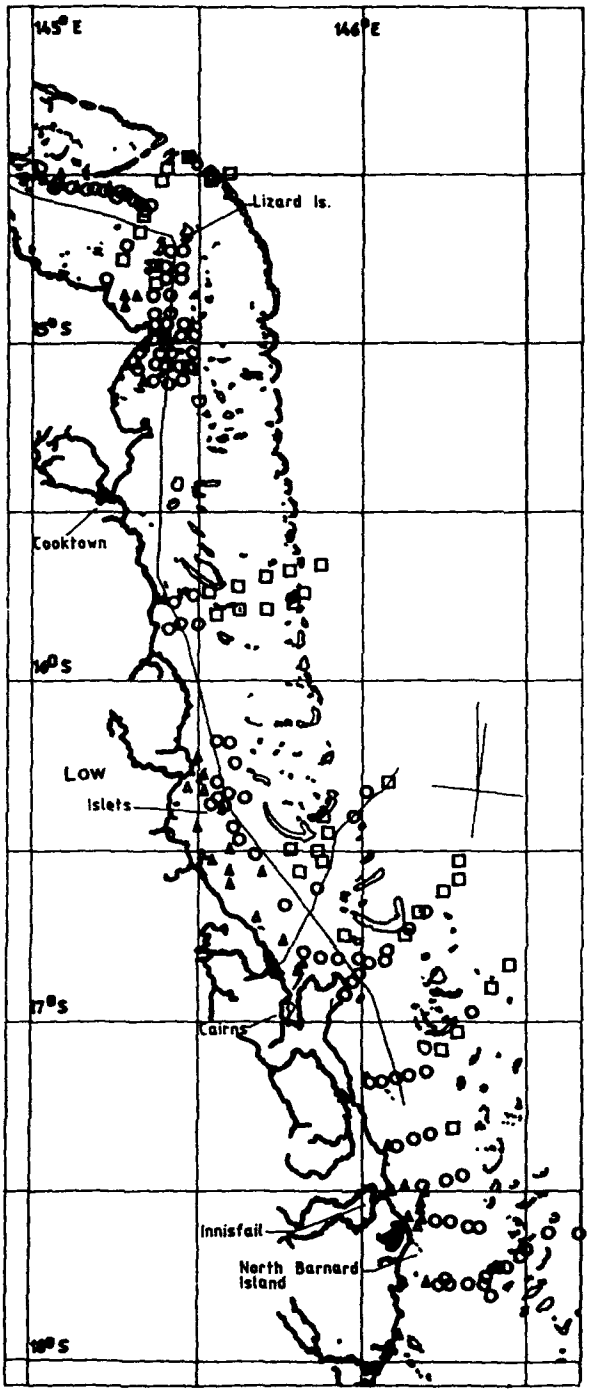


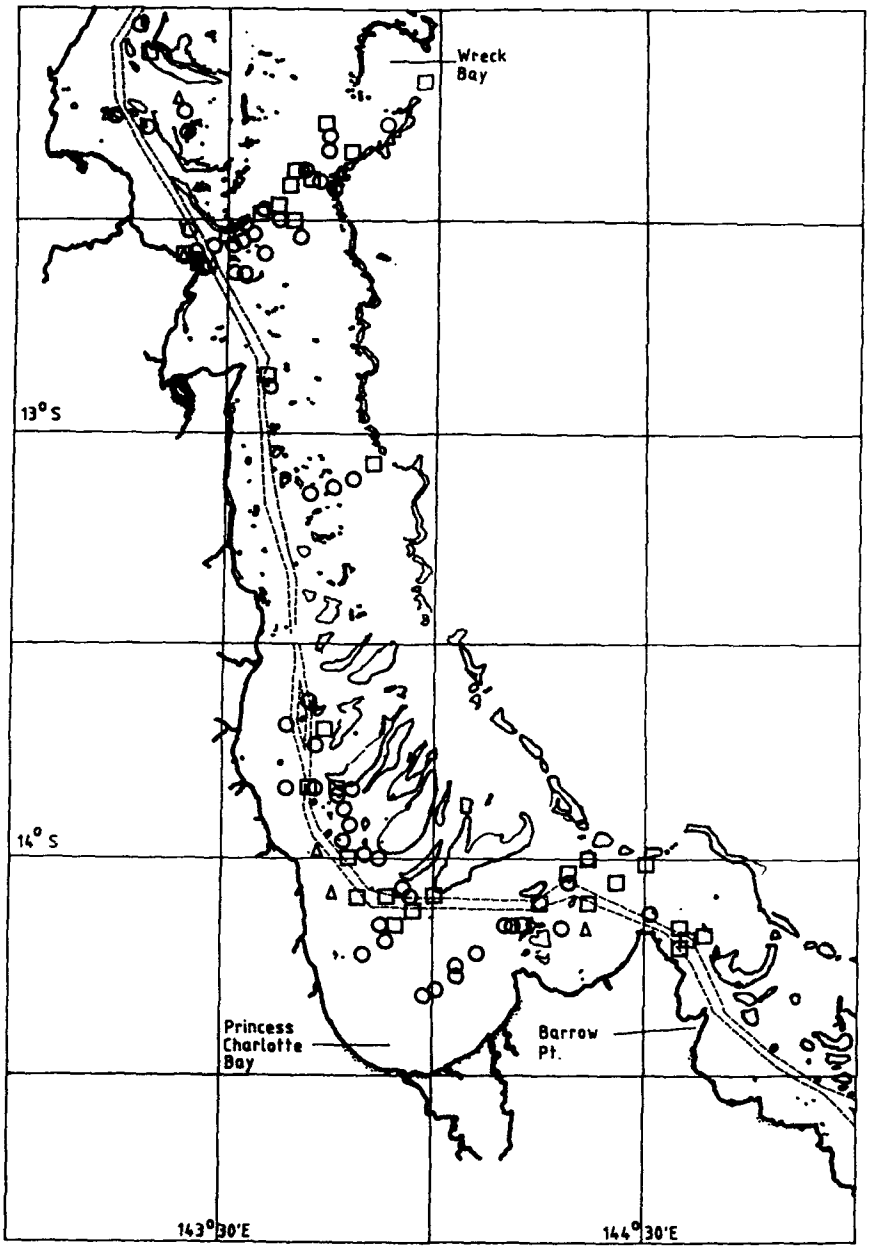
Figure 1: Histograms of Secchi depth variations off north Queensland. (a) Site 1 off Townsville, for 2 years. % < 5 m = 66; % < 10 m = 98; Av. = 4.7 m; σ = 2.2 m. (b) Site 2 off Townsville, for 3 years. % < 5 m = 0; % < 10 m = 10; Av. = 15.4 m; σ = 4.6 m. (c) Site 3 off Townsville, for 2 years. % < 10 m = 0; Av. = 20.6 m; σ = 5.9 m. (d) Low Islets, for 1 year. % < 5 m = 9; % < 10 m = 49. Av. = 12 m; σ = 5.5 m. (Orr 1933).



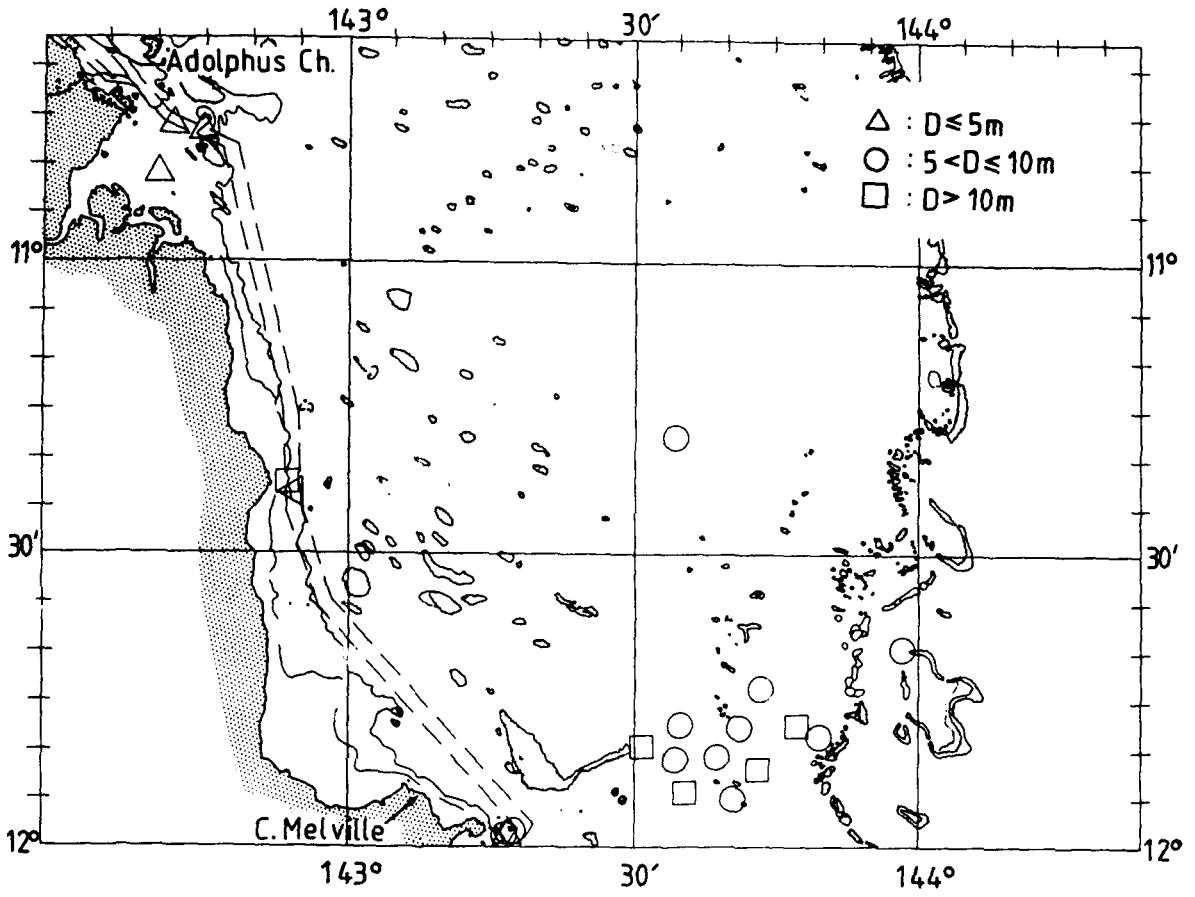
Map 1: *Great Barrier Reef: Cairns to Mackay 17°S to 21°S. Contours are for water depths of 10, 20 and 100 fm. Pluses indicate the monitoring stations at which the data used for the histograms of Figure 1 were obtained.*



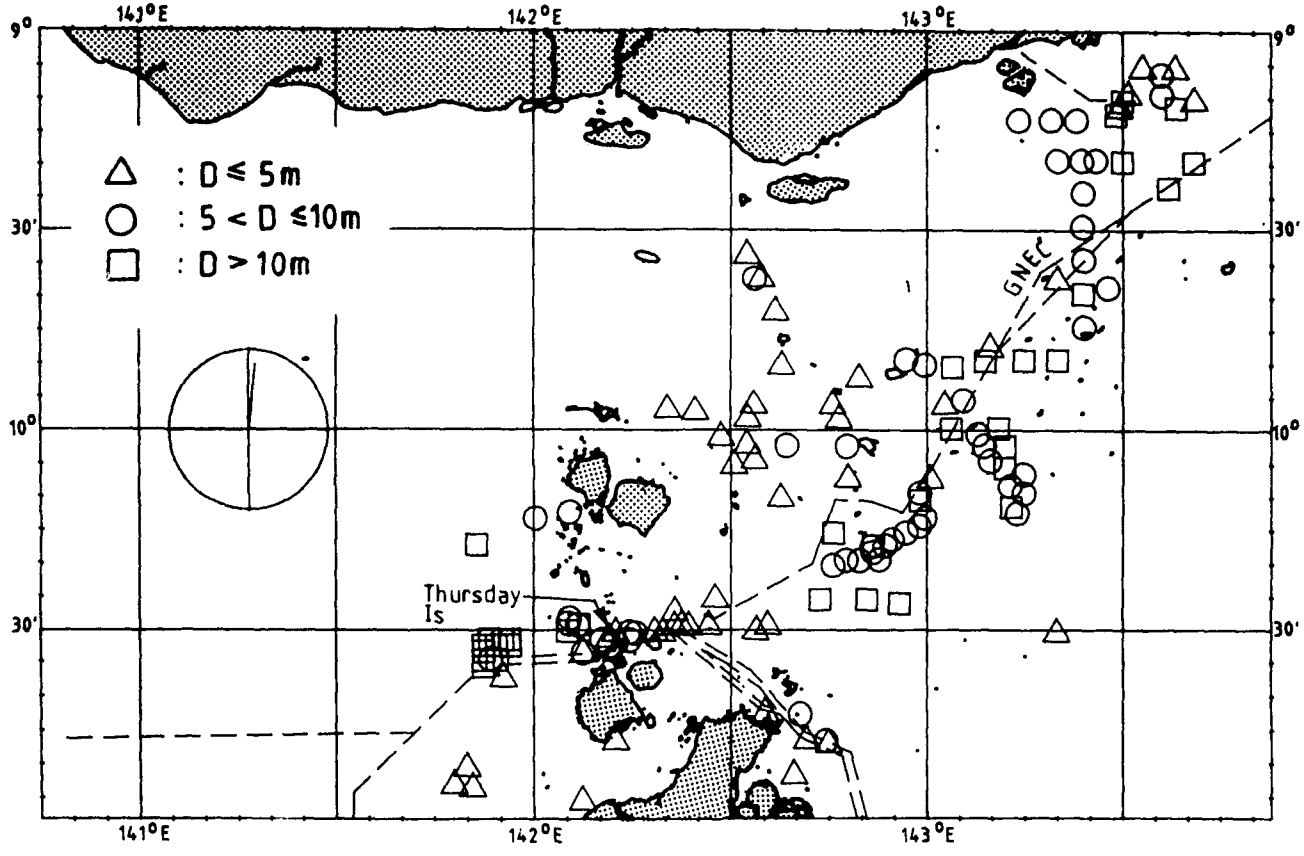
Map 2: Great Barrier Reef: Lizard Is. to Innisfail 14°S to 18°S. Contours, offshore are for 6 fm and 10 fm water depths. Dashed lines are principal shipping routes. Principal reefs are indicated. $\Delta : D \leq 5\ m$; $O : 5\ m < D \leq 10\ m$; $\square : D > 10\ m$.



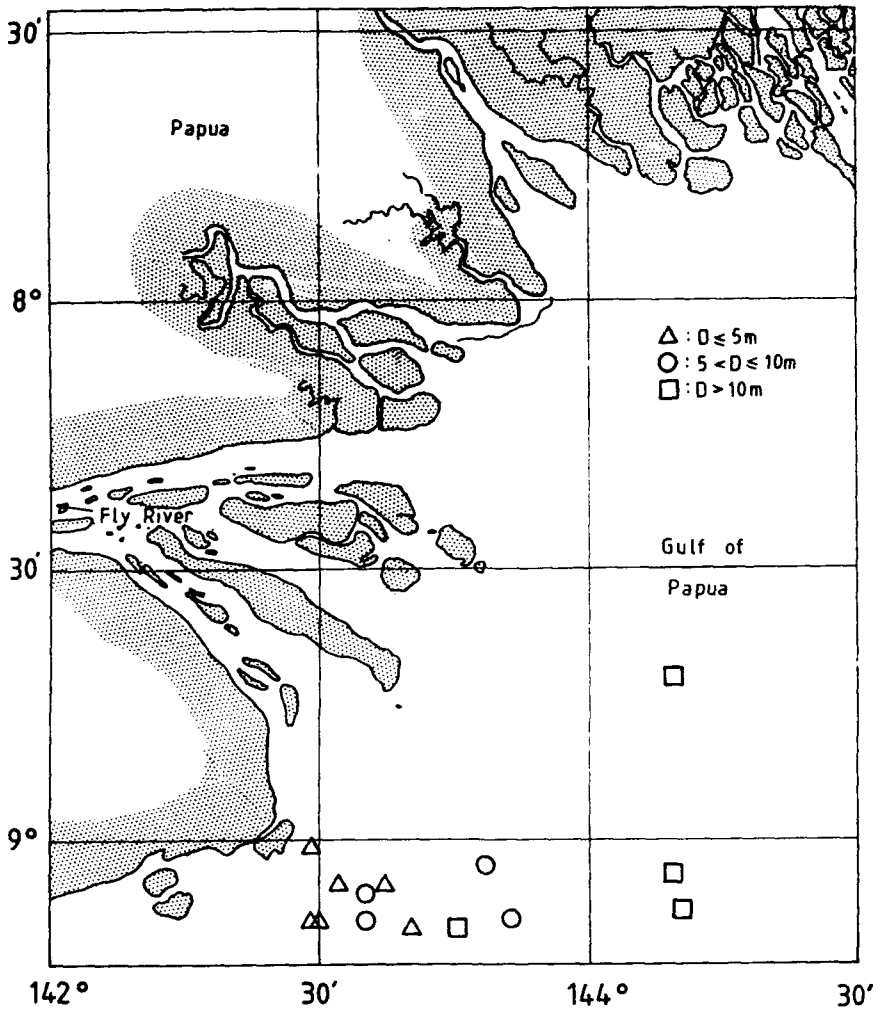
Map 3: Great Barrier Reef: Wreck Bay to Barrow Pt. 12°S to 15°S. Contours, offshore are for 3 fm and 6 fm water depths. Dashed lines are principal shipping routes. Principal reefs are indicated. $\Delta : D \leq 5\ m;\ O : 5\ m < D \leq 10\ m;\ \square : D > 10\ m.$



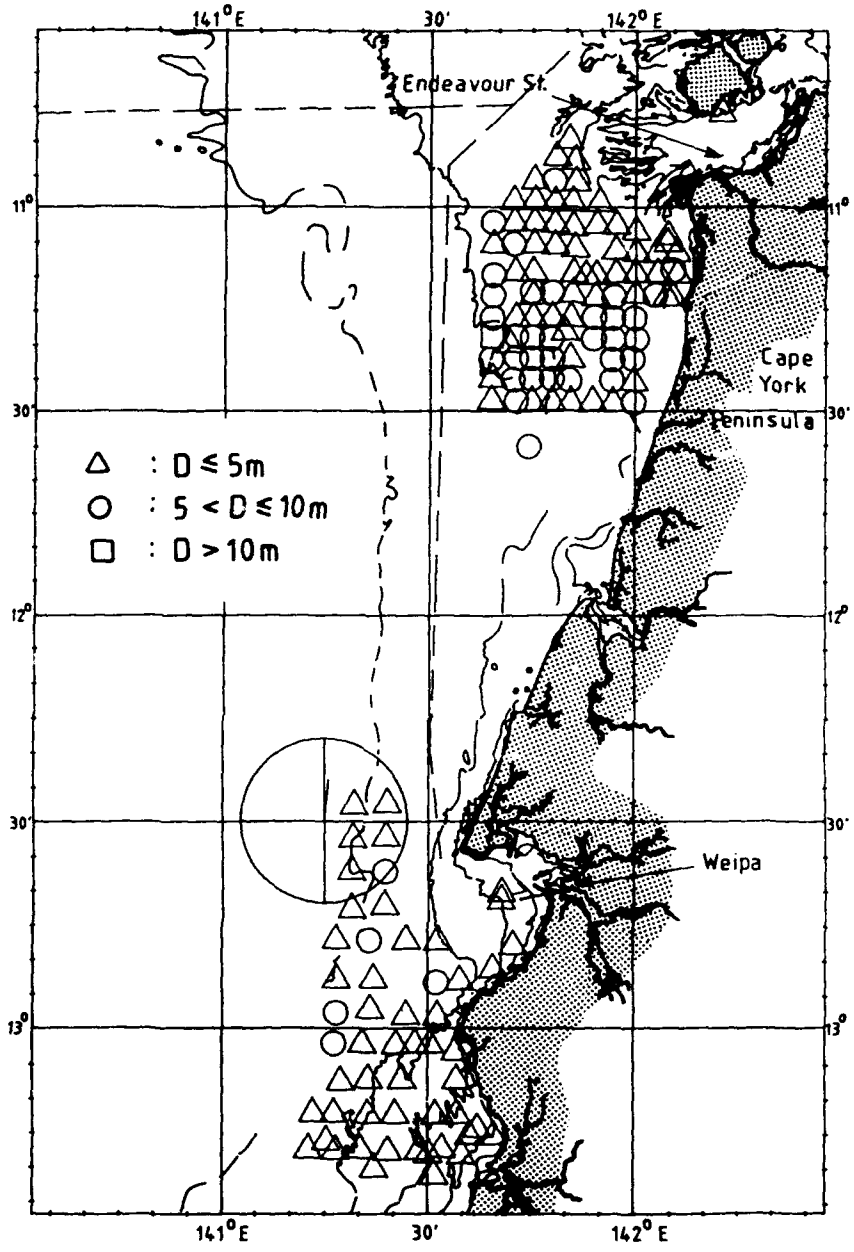
Map 4: *Great Barrier Reef: Adolphus Channel to C. Melville 10°30'S to 12°S. Contours, offshore are for 6 fm and 10 fm water depths. Dashed lines are principal shipping routes. Principal reefs are indicated.*



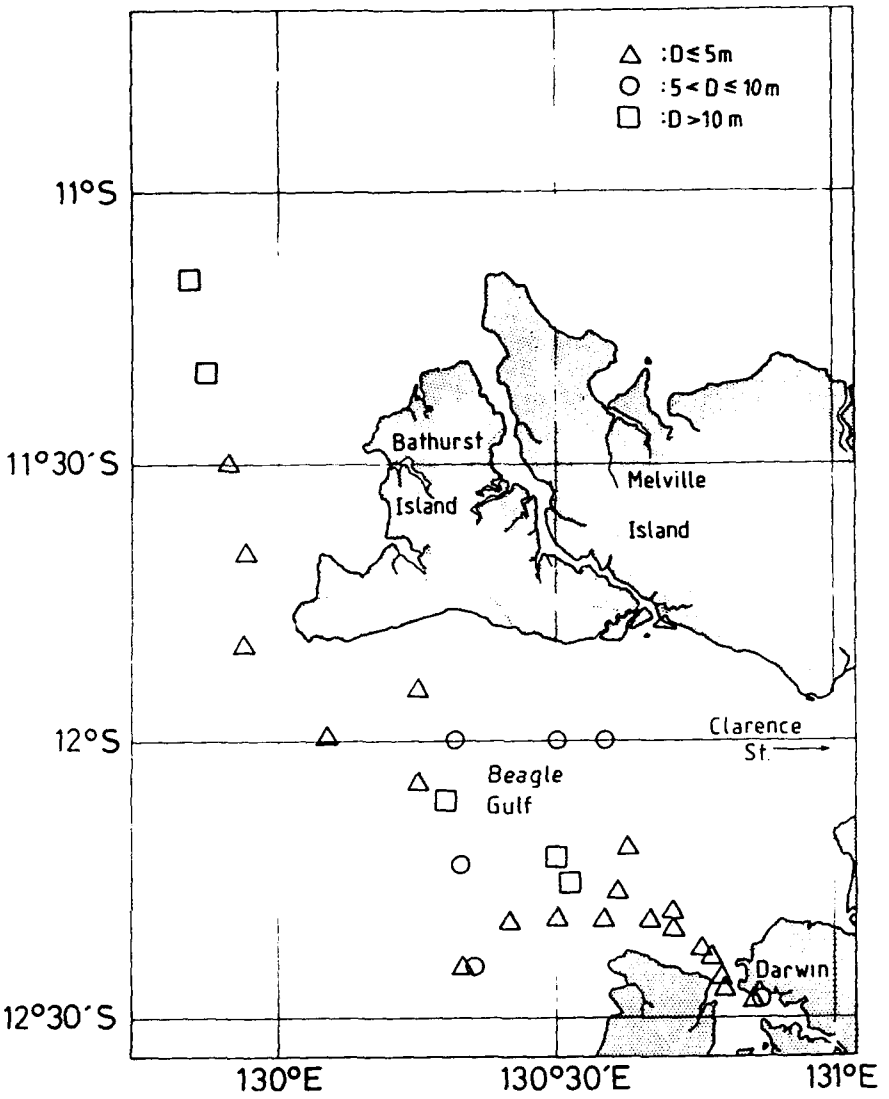
Map 5: *Torres Strait. Dashed lines are principal shipping routes.*



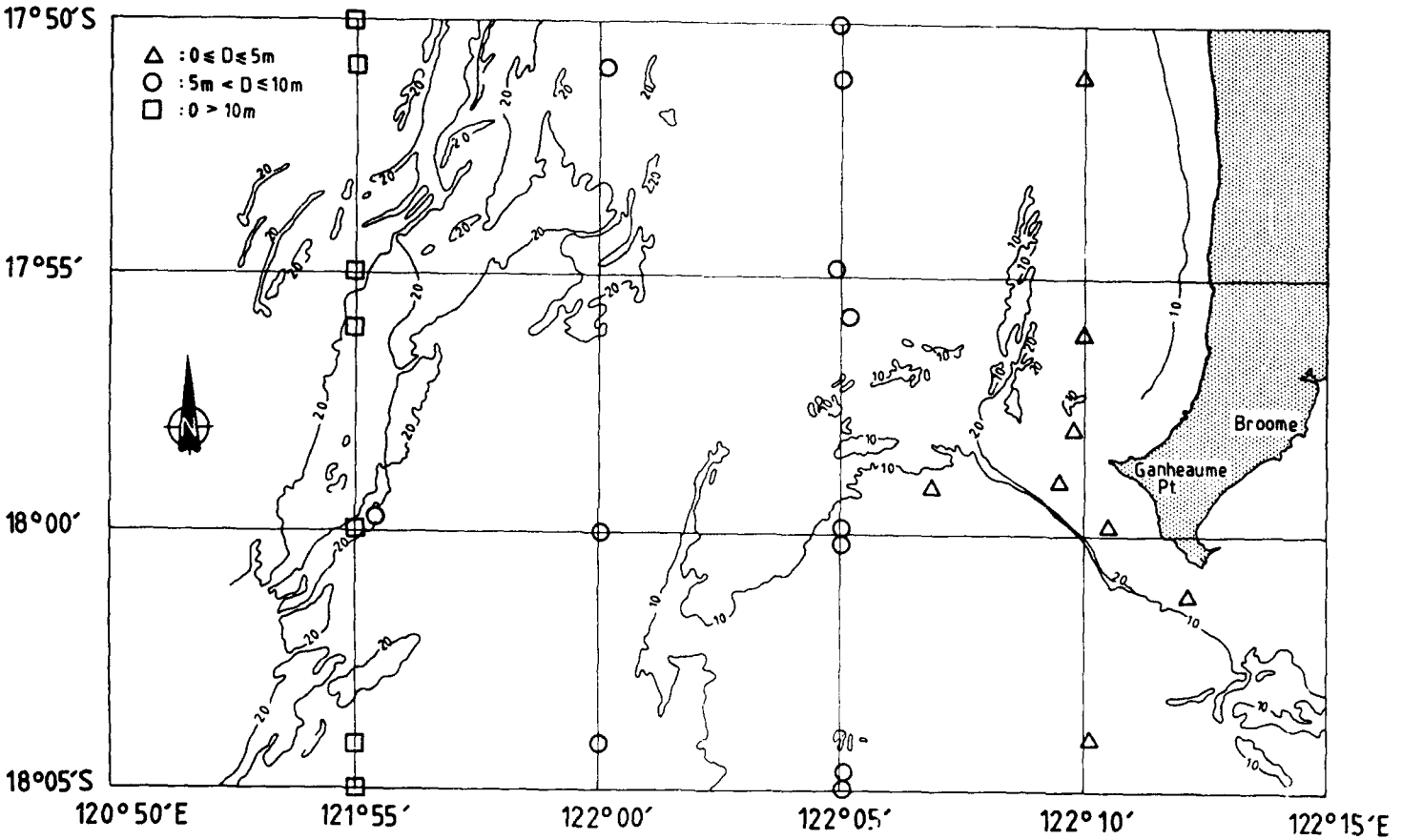
Map 6: Off Fly River.



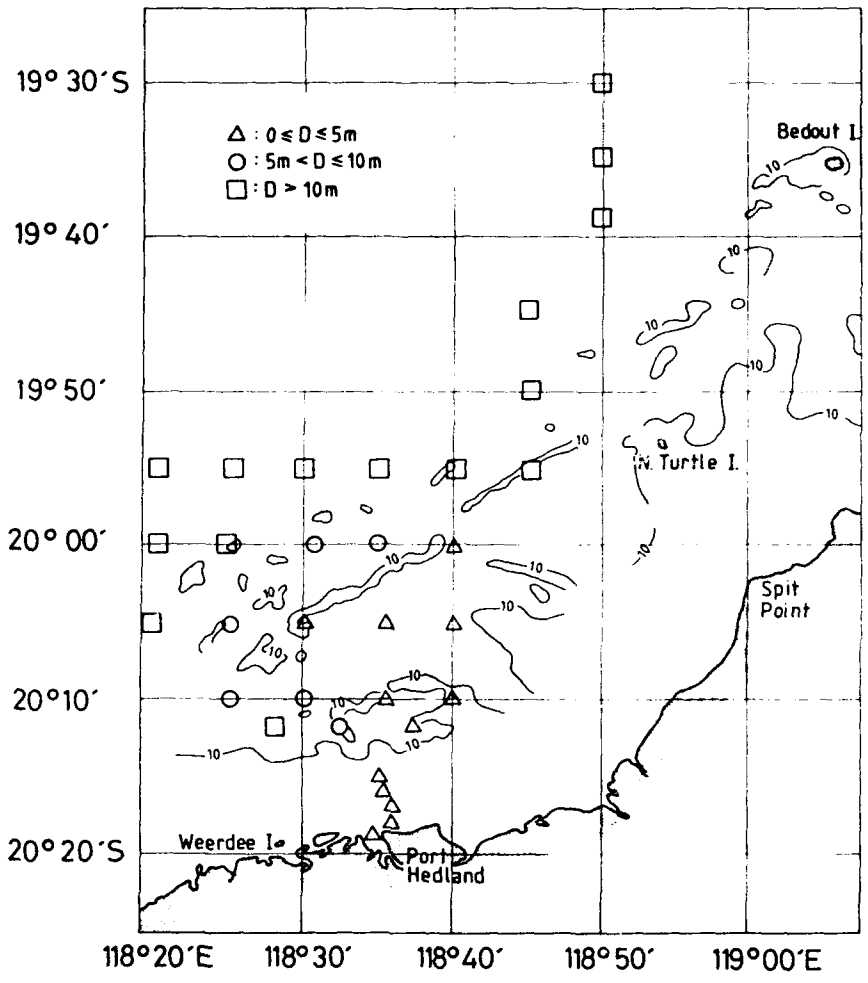
Map 7: Eastern Gulf of Carpentaria - Endeavour Strait to Weipa. Contours, offshore are for 3, 6, 10 and 20 fm water depths. Dashed lines are principal shipping routes.



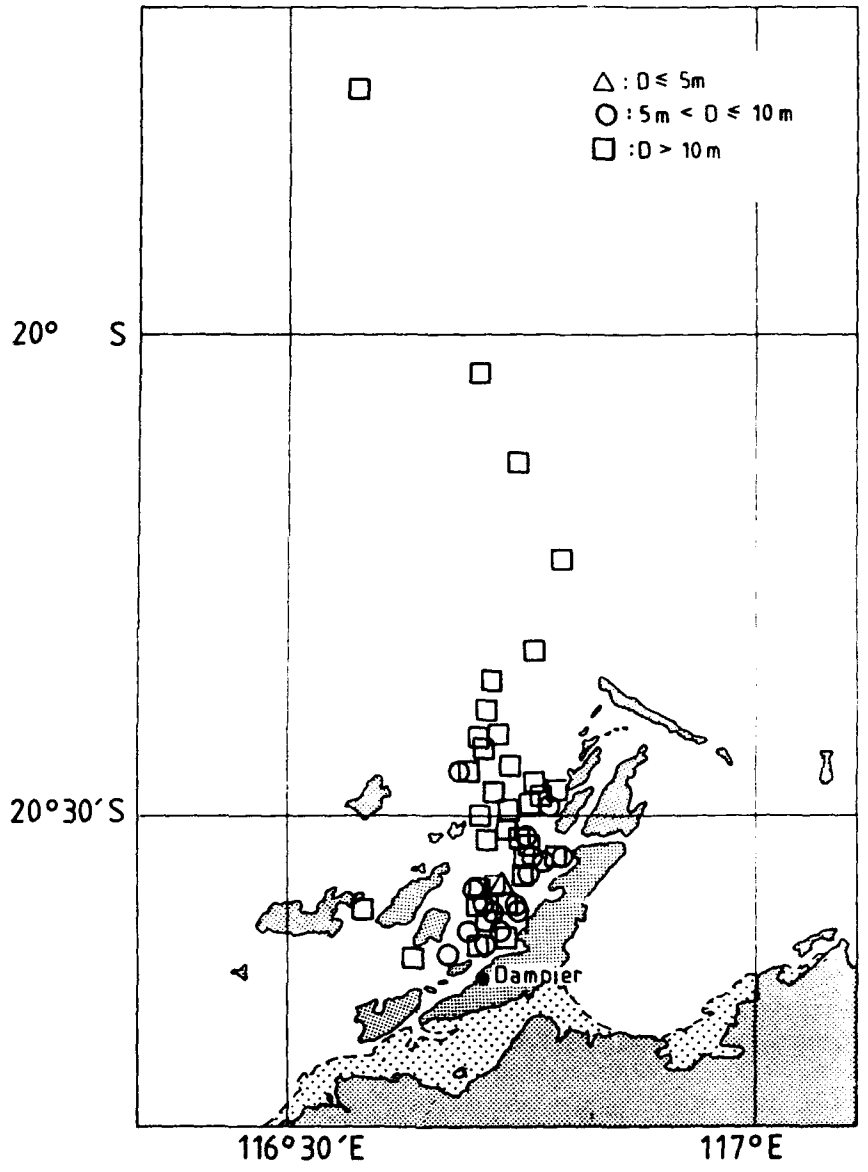
Map 8: Approaches to Darwin.



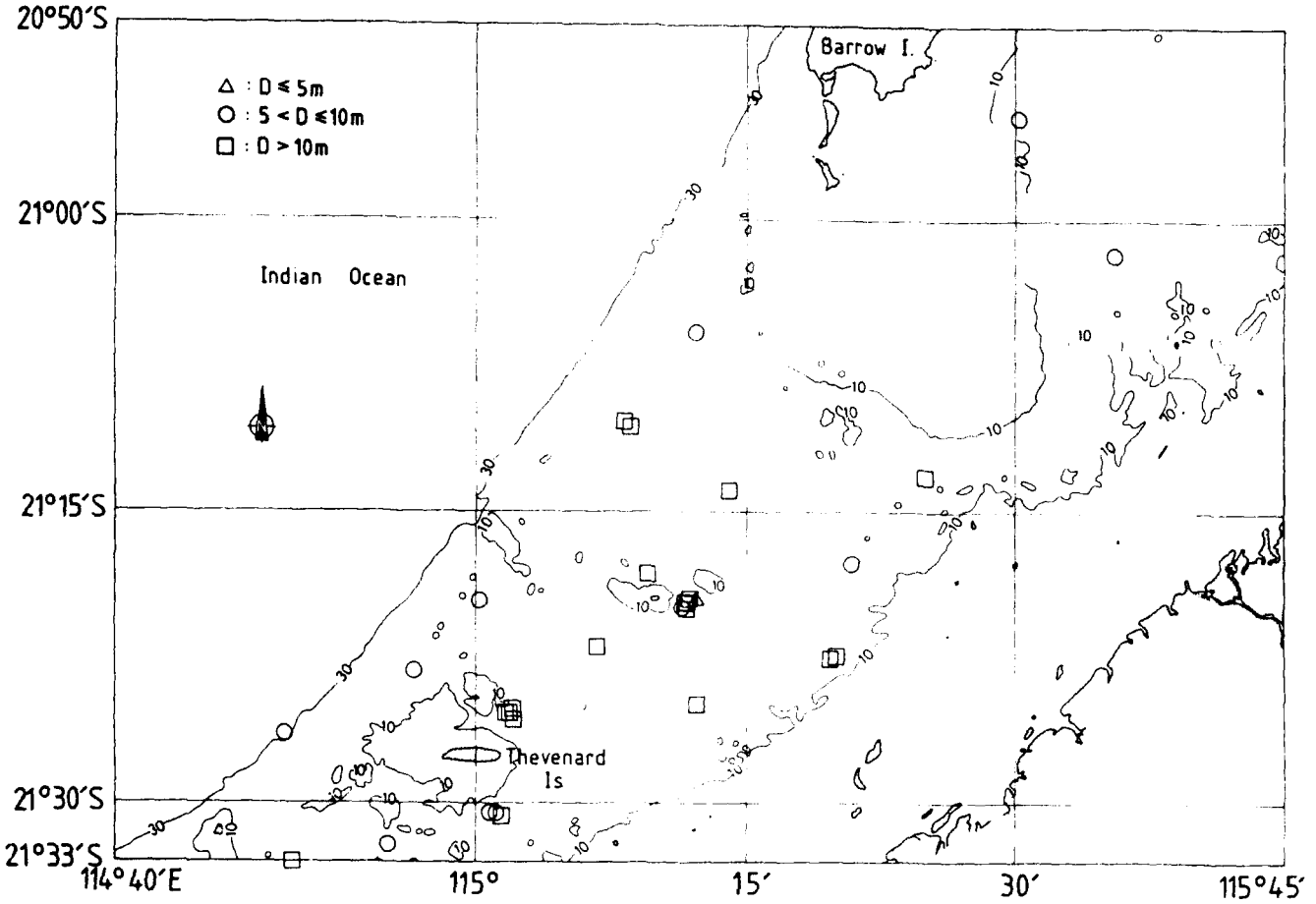
Map 9: *The Northwest: Approaches to Broome (depth contours are in metres).*



Map 10: The Northwest: Approaches to Port Hedland (depth contours are in metres).



Map 11: The Northwest: Approaches to Dampier.



Map 12: *The Northwest: Barrow Is. to Thevenard Is. (depth contours are in metres).*

SECURITY CLASSIFICATION OF THIS PAGE **UNCLASSIFIED**

REPORT NO.	AR NO.	REPORT SECURITY CLASSIFICATION
MRL-TN-638	AR-008-262	Unclassified

TITLE

Distribution of turbidity in Australian tropical waters

AUTHOR(S)
P.J. Mulhearn

CORPORATE AUTHOR
DSTO Materials Research Laboratory
PO Box 50
Ascot Vale Victoria 3032

REPORT DATE	TASK NO.	SPONSOR
August, 1993	DST 89/225	DSTO

FILE NO.	REFERENCES	PAGES
G6/4/8-4308	14	27

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Chief, Maritime Operations Division

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KEYWORDS

Secchi depth
Secchi disc values
Turbidity
Underwater visibility

ABSTRACT

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P.J. Mulhearn

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Miss A.C. Cerneaz, MOD-Sydney
Director, Oceanography and Meteorology, Maritime Headquarters, Potts Point, NSW 2011
Lcdr M. Rutherford, Officer-in-Charge, Naval Weather and Oceanographic Centre, Naval Air Station, Nowra NSW 2540
Cmdr M. Welford, Mine Warfare Systems Project Director, Campbell Park CP2-2-19
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